The νBDX-DRIFT Experiment to Study CEνNS and New Physics at Fermilab

Dan Snowden-Ifft / Occidental College
May 11, 2023

The νBDX-DRIFT Collaboration

Occidental College
Dan Snowden-Ifft
Jean-Luc Gauvreau

University of New Mexico
Dinesh Loomba

Texas A&M University
Louis Strigari
Bhaskar Dutta
Doojin Kim

INFN-GE
Genoa University
Marco Battaglieri
R. DE Vita
M. Bondi
M. Spreafico

Universidad Technica Federico Santa Maria
Diego Aristizabal Sierra

Canisius College
Mike Wood

INFN-CT
University of Messina
M. de Napoli
G. Mandaglio
S. Sgrazzi
A. Fulci
A. Pilloni

INFN-RM2
University of Roma Tor Vergata
A. D'Angelo

Zuckerman Post-Doctoral Scholar

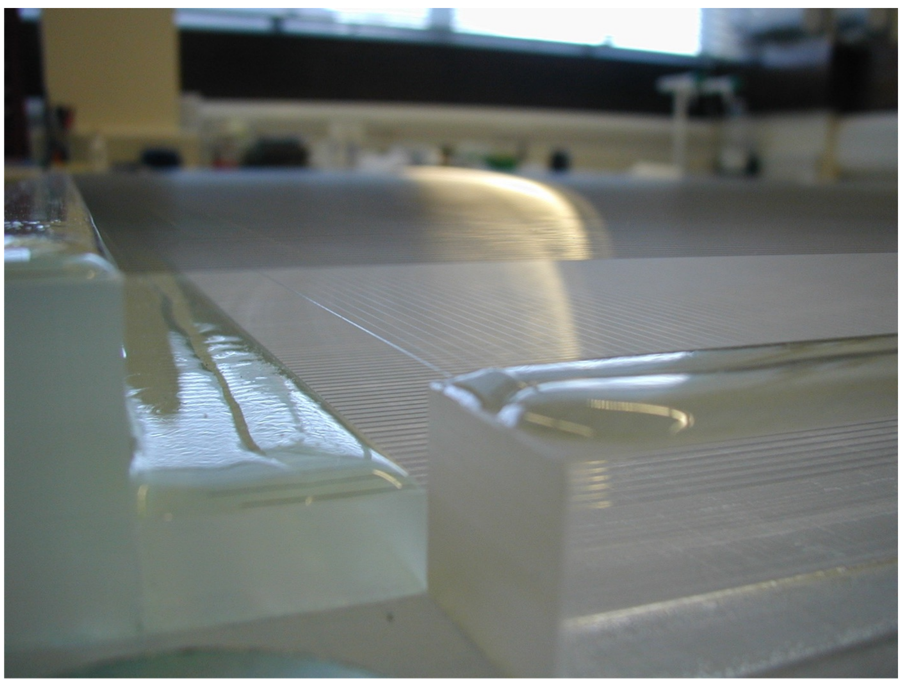
J. Barrow

DRIFT: Lightning Summary

Started = 1998, US/UK

Directional WIMP dark matter detector

40 Torr, 1 m^3 gaseous detector



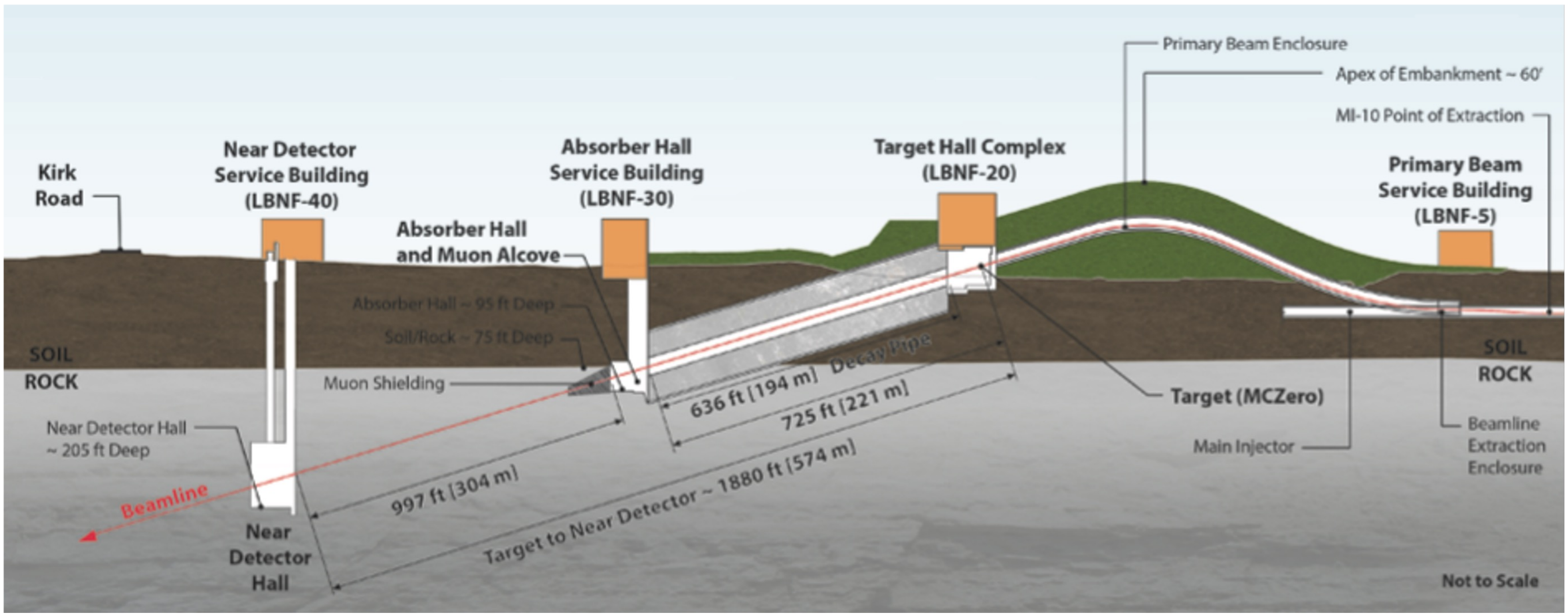
Unique and robust technology

Low energy (35 keV) threshold for nuclear recoils

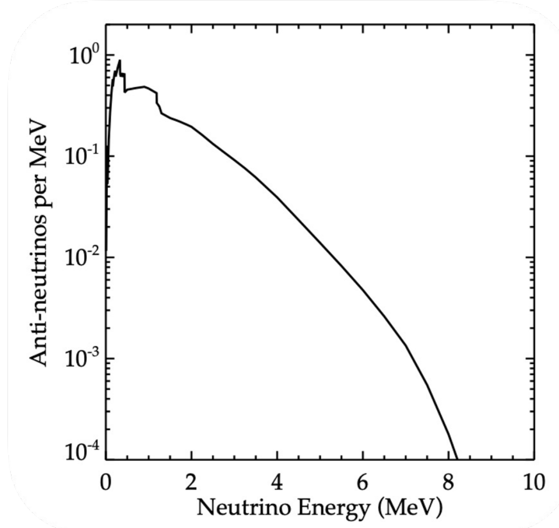
Low background

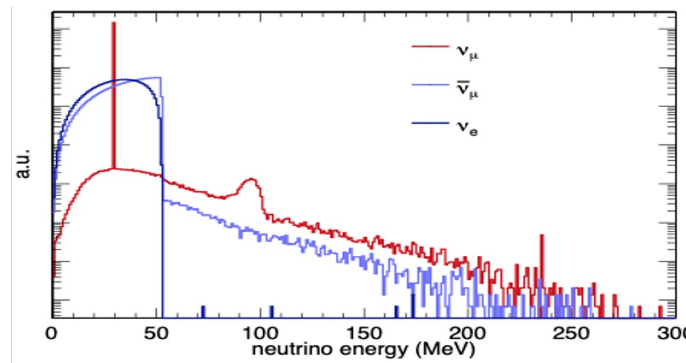
AstroPle, 91, 2017

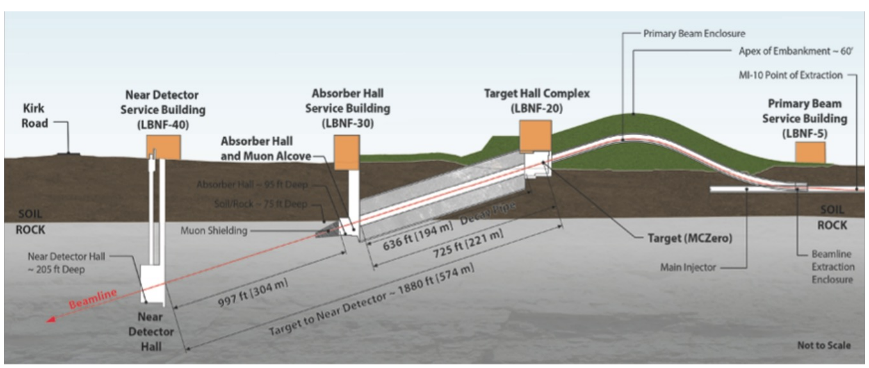
νBDX-DRIFT at DUNE

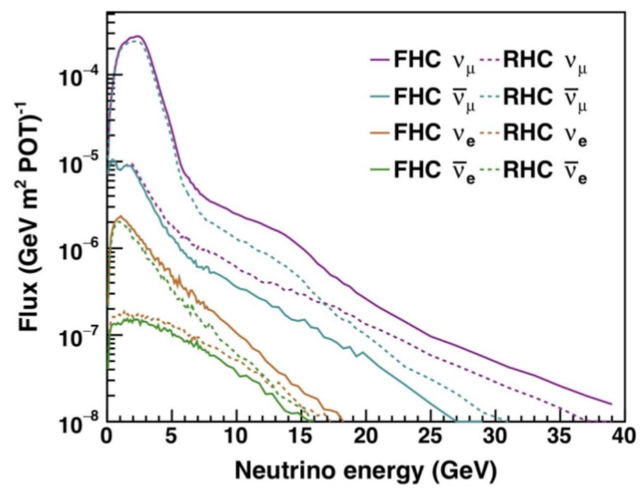


Sources for CEνNS



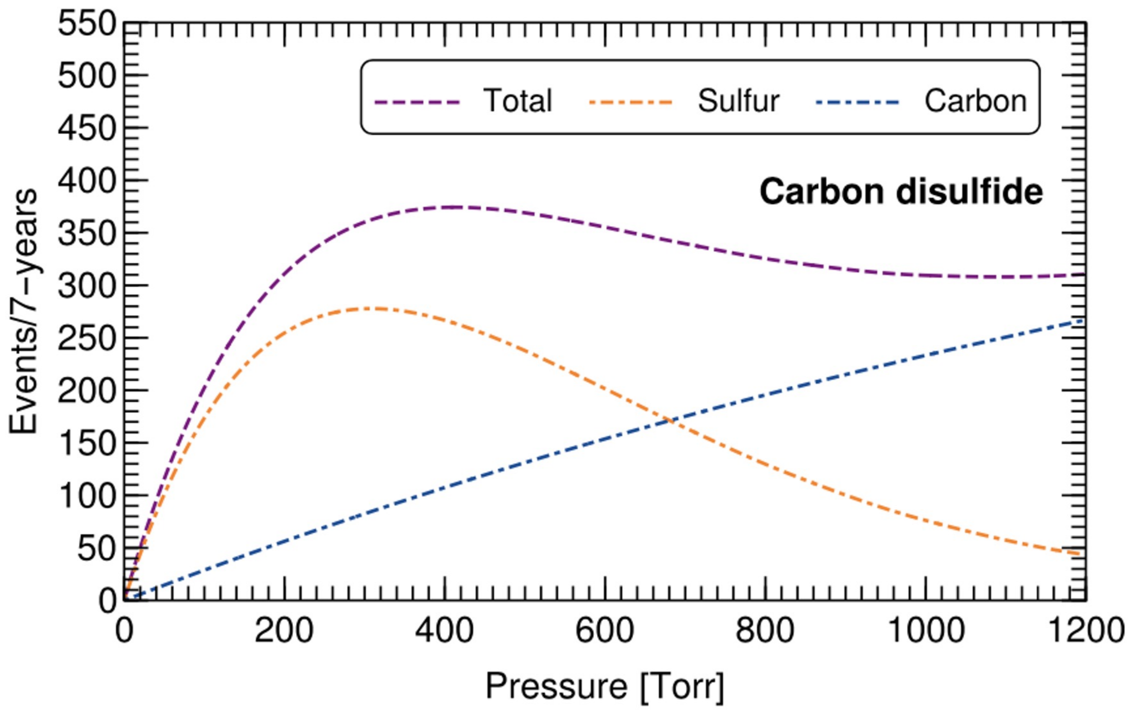






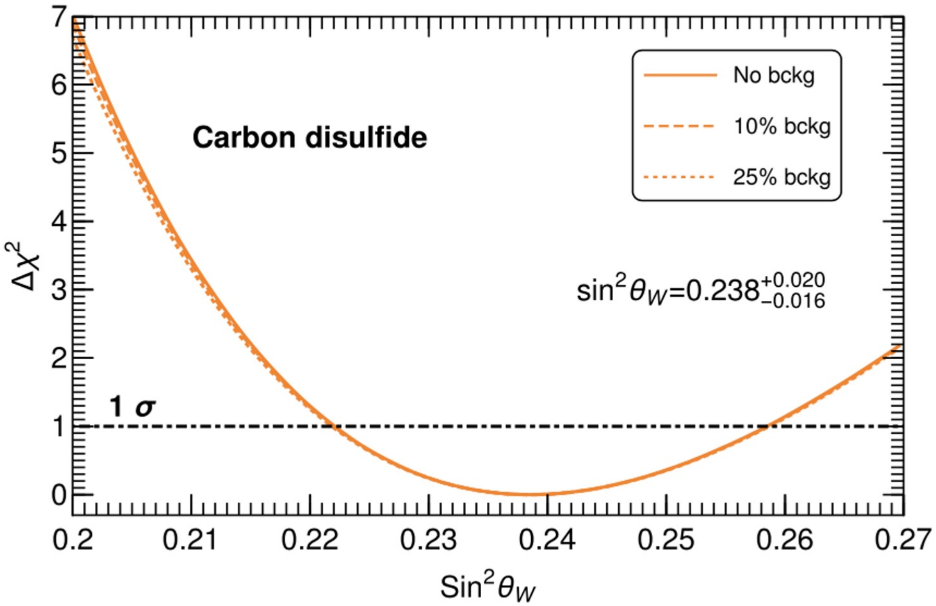
CEνNS Physics – Event Rates

- Recoil energy threshold proportional to pressure
- Max rate @ 400 Torr CS_2
- Significant detection, ~400 events for 7 yrs with 10 m^3
- Different nuclei possible
- Directionality for signature



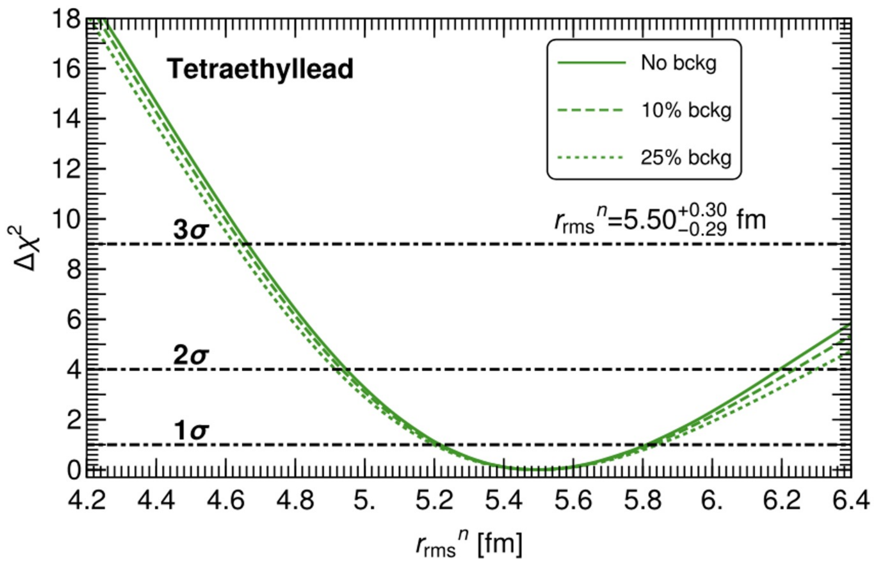
PRD 104, 2021, arXiv:2103.10857, Aristizabal-Sierra et al.

CEνNS Physics - Measurements



- Measurement of the weak mixing angle on S to 8%

- Measurement neutron distribution in Pb to 5% and skin
- Larger neutrino energy => Sufficient stats at high Q
- Systematics on form factor are small
- Comparison with PREX



PRD 104, 2021, arXiv:2103.10857, Aristizabal-Sierra et al.

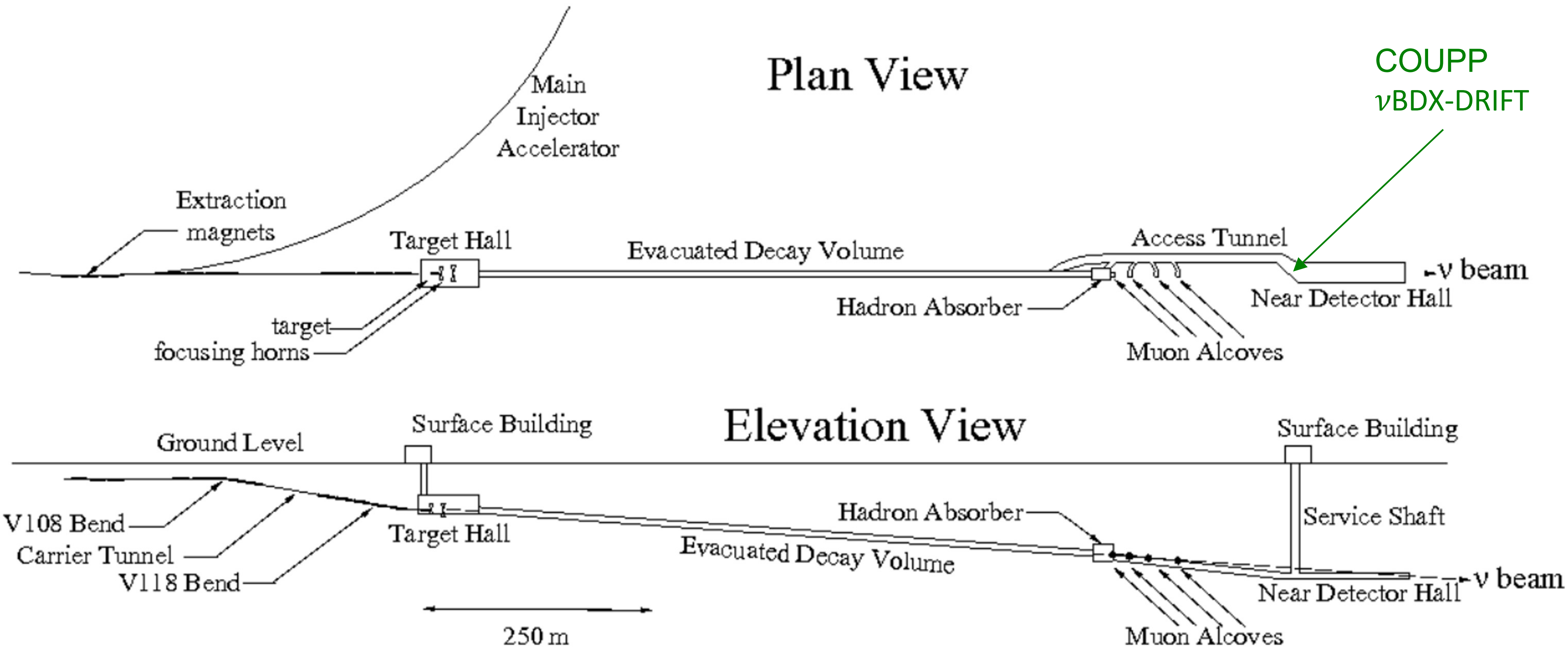
Other Neutrino – Nucleus Events

- νBDX-DRIFT can image more than the nuclear recoils
- i.e. non-CEνNS events are also targets for investigation
- i.e. Neutrino – Nucleus interactions at high momentum transfer
- i.e. “inelastic” events (quasielastic reactions, others possible)
- Study kinematics of nuclear remnants, multidifferential xsecs
- Can be compared to GENIE, other generators—constrain FSIs

Beyond the Standard Model physics

- Low background and directional sensitivities can be utilized to investigate BSM physics
- Light dark-matter and axion-like particles
- Dark matter and neutrino inelastic up-scattering processes including directionality: primary recoil + secondary (displaced) decay
- Various types of dark matter and neutrino interactions
- Decays of various types of light mediators
- Complementarity with DUNE

νBDX-DRIFT at NuMI



Backgrounds - Benchmarking

- Used COUPP 2009 nuclear recoil data to benchmark the simulation

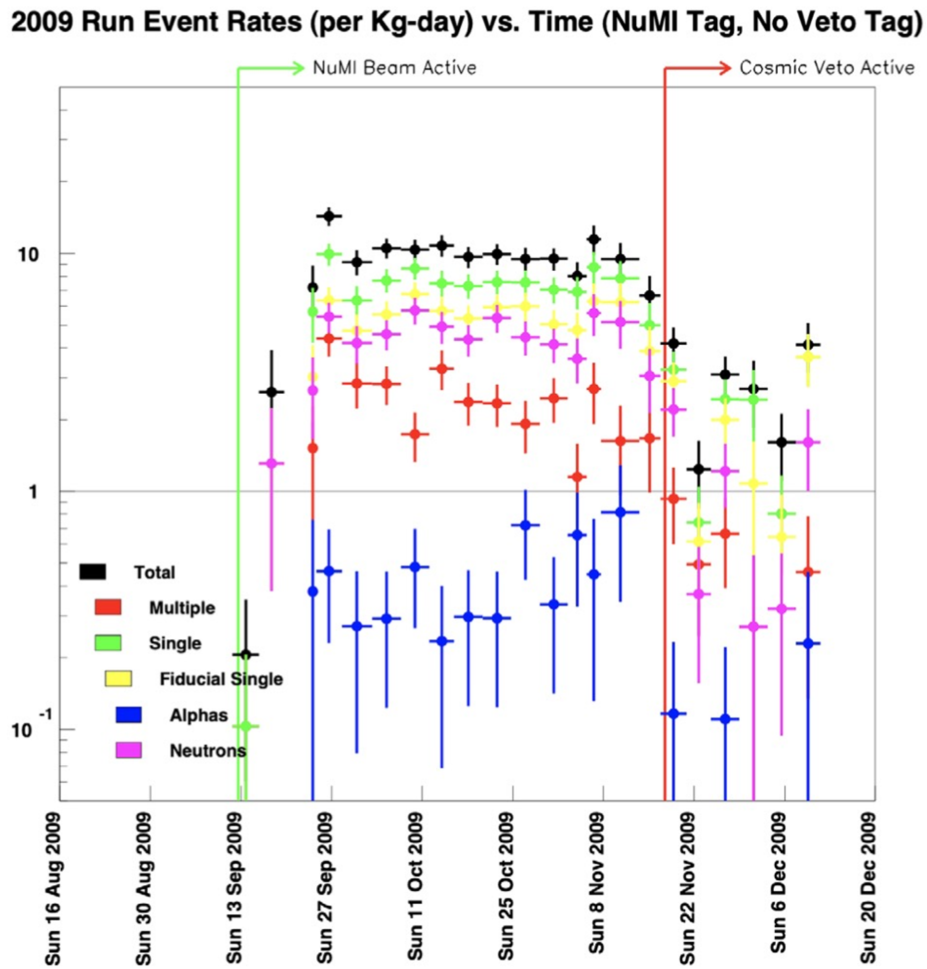


FIG. 1. The 2009 COUPP bubble formation data tagged to the beam pulse. Published here with the permission of the COUPP Collaboration.

Backgrounds - Benchmarking

- Used COUPP 2009 nuclear recoil data to benchmark the simulation
- COUPP (unpublished) measured 4.56 +/- 0.19 events/kg/day

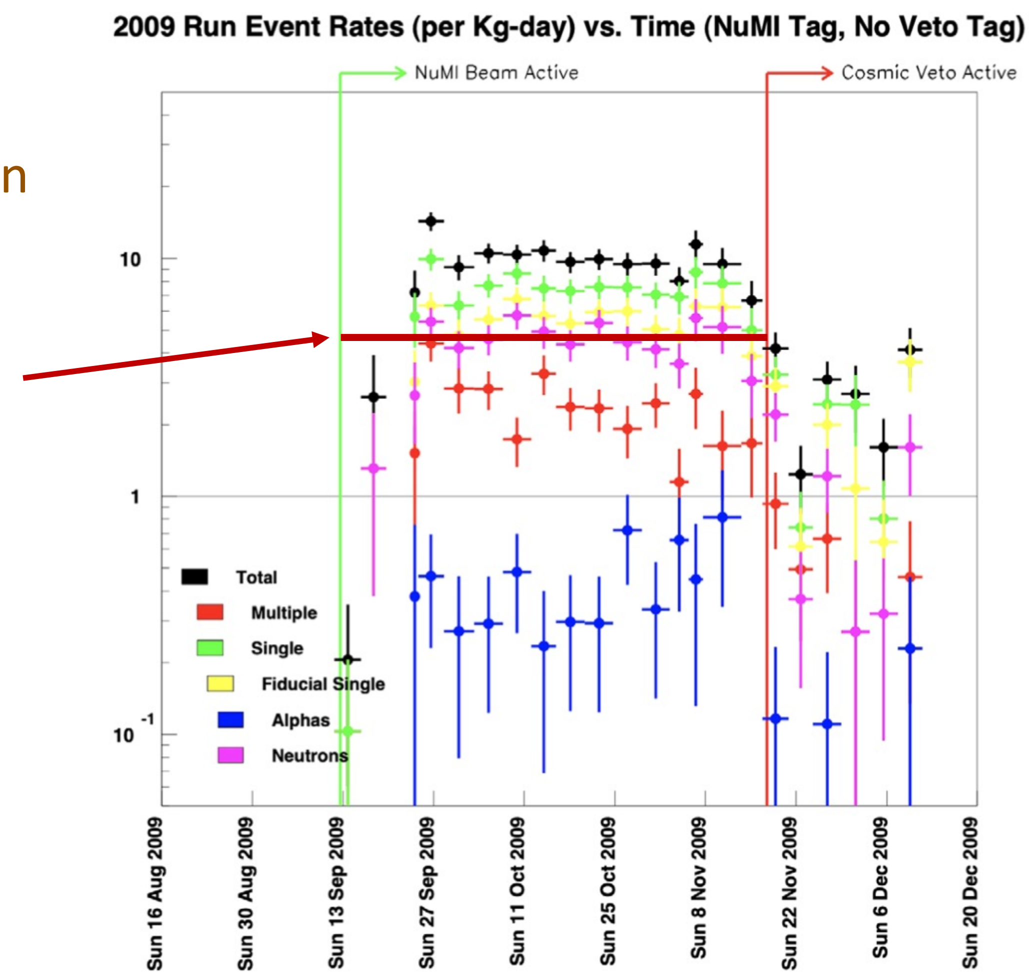


FIG. 1. The 2009 COUPP bubble formation data tagged to the beam pulse. Published here with the permission of the COUPP Collaboration.

Backgrounds - Benchmarking

- Used COUPP 2009 nuclear recoil data to benchmark the simulation
- COUPP (unpublished) measured 4.56 +/- 0.19 events/kg/day
- Genie/GEANT predict (3.006, 3.356) +/- 0.023 events/kg/day
- 30% low

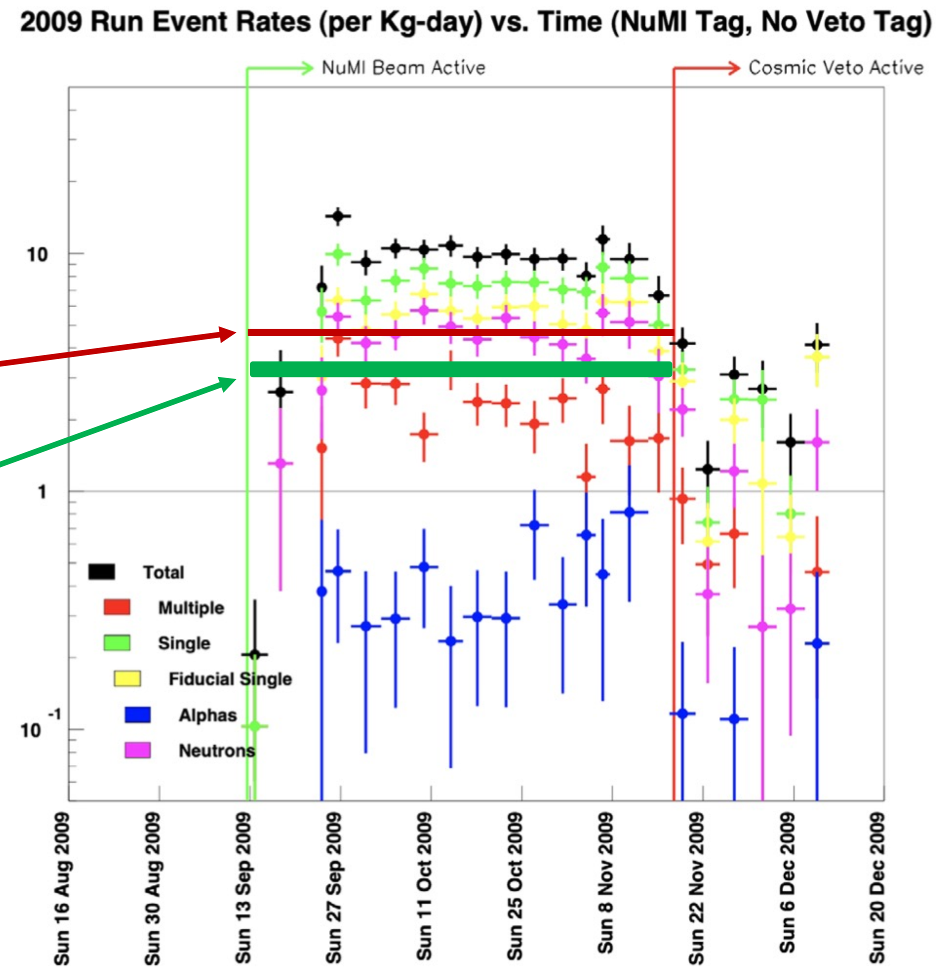


FIG. 1. The 2009 COUPP bubble formation data tagged to the beam pulse. Published here with the permission of the COUPP Collaboration.

PRD 107, 2023, arXiv:2210.08612, Aristizabal-Sierra et al.

Backgrounds - Predicted

TABLE IV. Output table shows neutron flux from different walls and background in the signal region. For details see Sec. IV.

Simulations output for neutron flux from the walls				
Beamline and mode	Upstream $[n^0/\mathrm{s}/\mathrm{m}^2]$	Sides $[n^0/\mathrm{s}/\mathrm{m}^2]$	Downstream $[n^0/\mathrm{s}/\mathrm{m}^2]$	Background $[\mathrm{events}/\mathrm{m}^3/\mathrm{year}]$
NuMI LE	0.0355	0.0204	0.0110	8.61 ± 0.62
NuMI HE	0.209	0.131	0.0727	54.9 ± 3.8
DUNE on-axis at 1.2 MW	0.101	0.0276	0.0524	23.3 ± 1.3
DUNE 39 m off-axis at 1.2 MW	0.000381	0.0000831	0.000162	0.0396 ± 0.0031

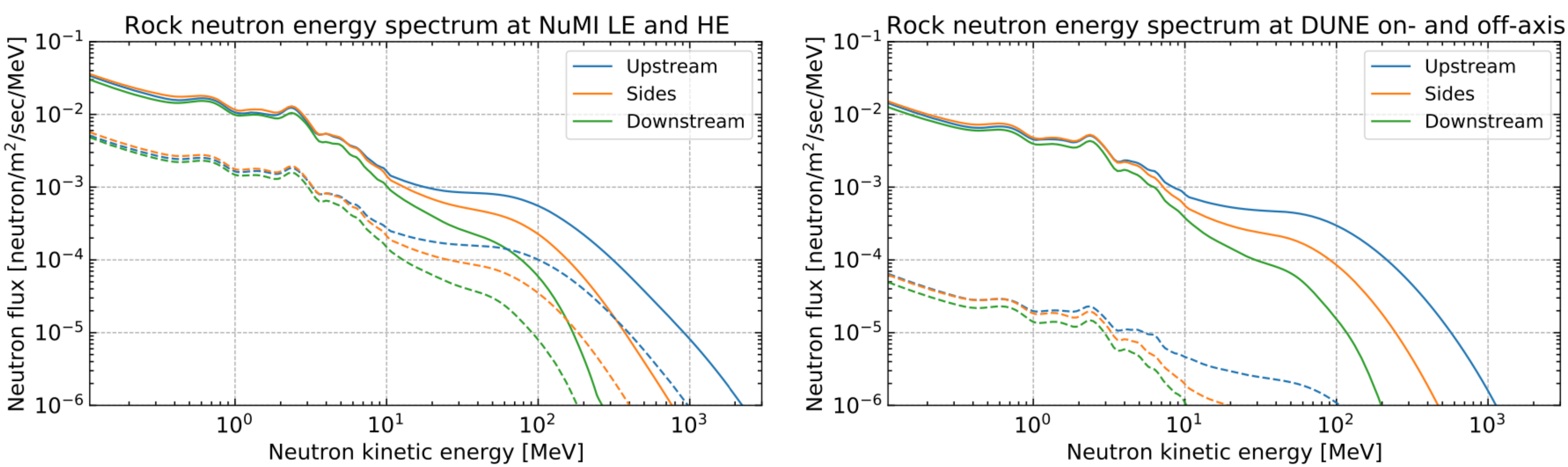


FIG. 6. The energy distribution of rock-neutrons generated in the four simulations of Table I. The blue lines show the spectra coming from the upstream wall. The orange lines show the spectra coming from the side walls. And the green lines show the spectra coming from the downstream wall. In the left graph, the solid (dashed) curves correspond to results obtained with the NuMI HE (LE) neutrino mode. In the right graph—instead—to results derived with the DUNE on-axis (off-axis) configuration.

Backgrounds - Predicted

ROCK NEUTRON BACKGROUNDS FROM FNAL NEUTRINO … PHYS. REV. D **107,** 013003 (2023)

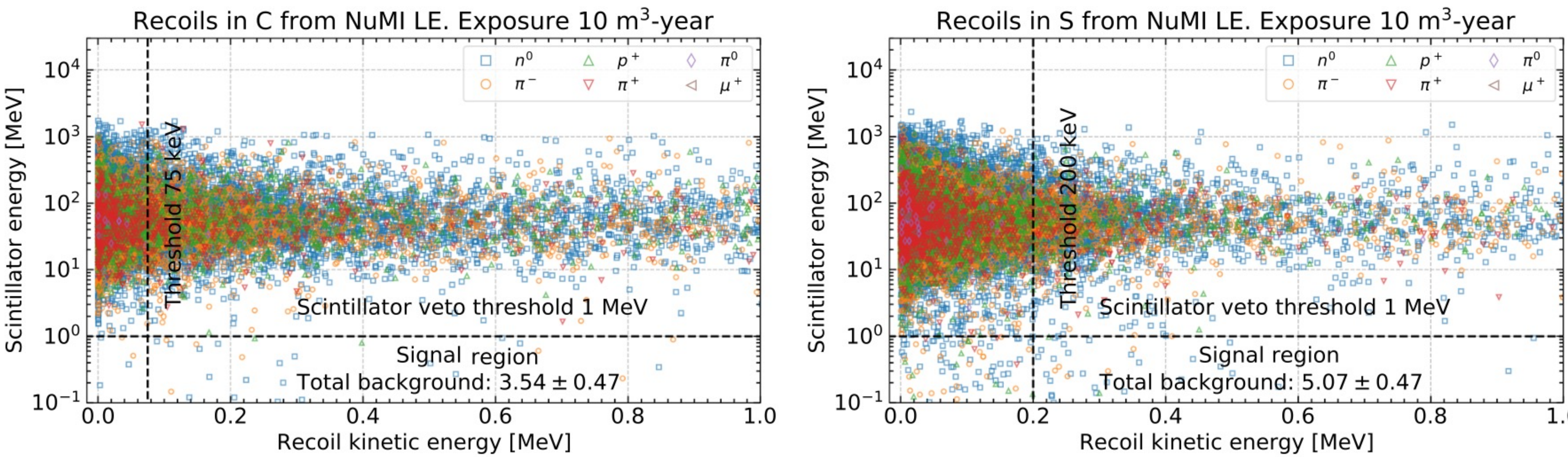
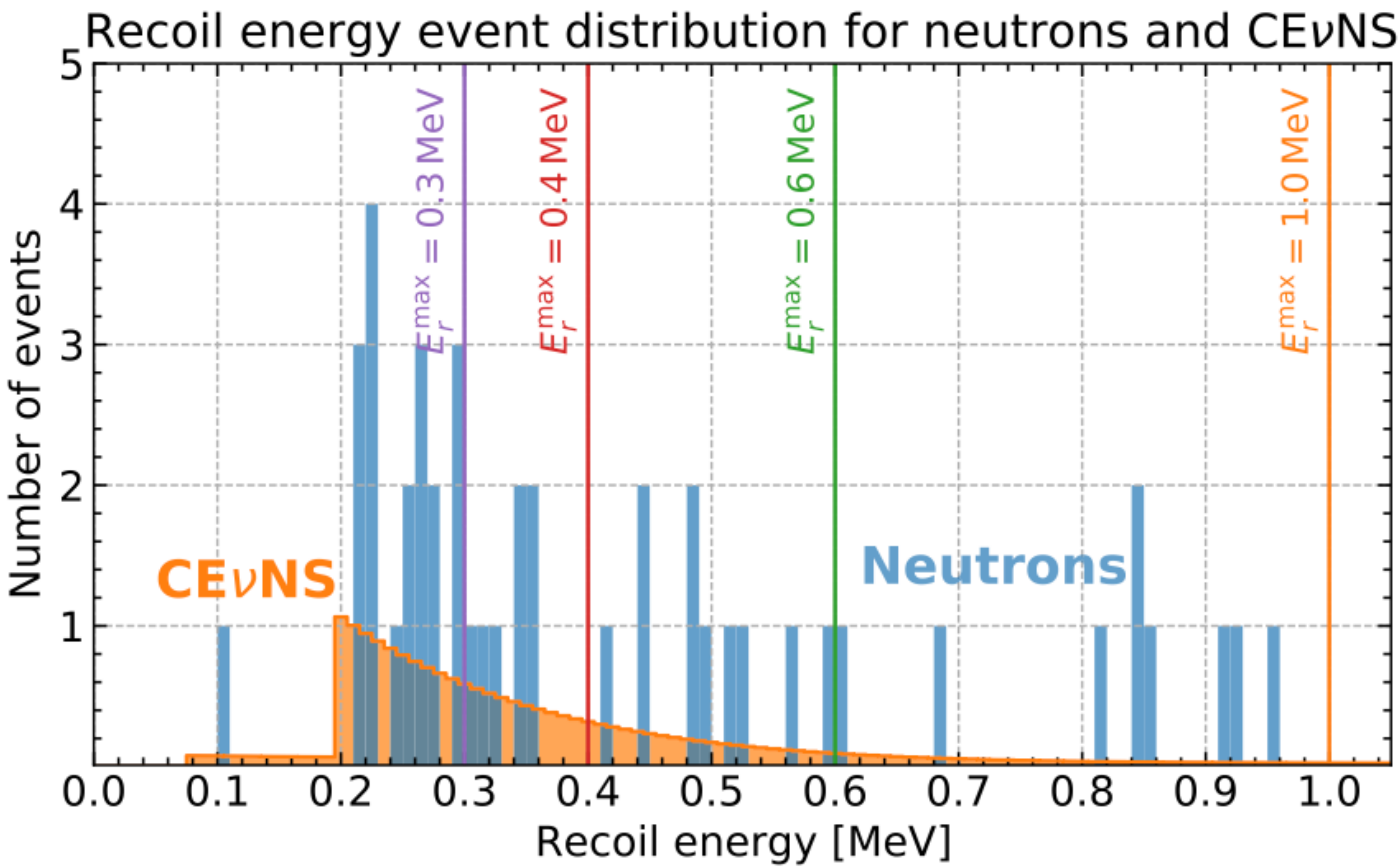


FIG. 8. Plots showing the distribution of recoil energies vs energy deposited in the scintillator with the neutrino-induced end-state particle responsible for the recoil shown in different colors. The left graph shows the results for C recoils while the right graph shows the S recoils. Both are heavily dominated by neutron end-states (about 63% for both target nuclei). The vertical dashed black lines indicate the recoil thresholds, 75 keV for C and 200 keV for S. The horizontal dashed black lines show the threshold for the scintillator veto, 1 MeV; events with larger energies are vetoed. The lower-right region therefore shows the signal region where either CEνNS or BSM recoils events would occur. The background rate, in events per m^3 per year, are shown there. The sum is shown in the fifth column of Table IV.

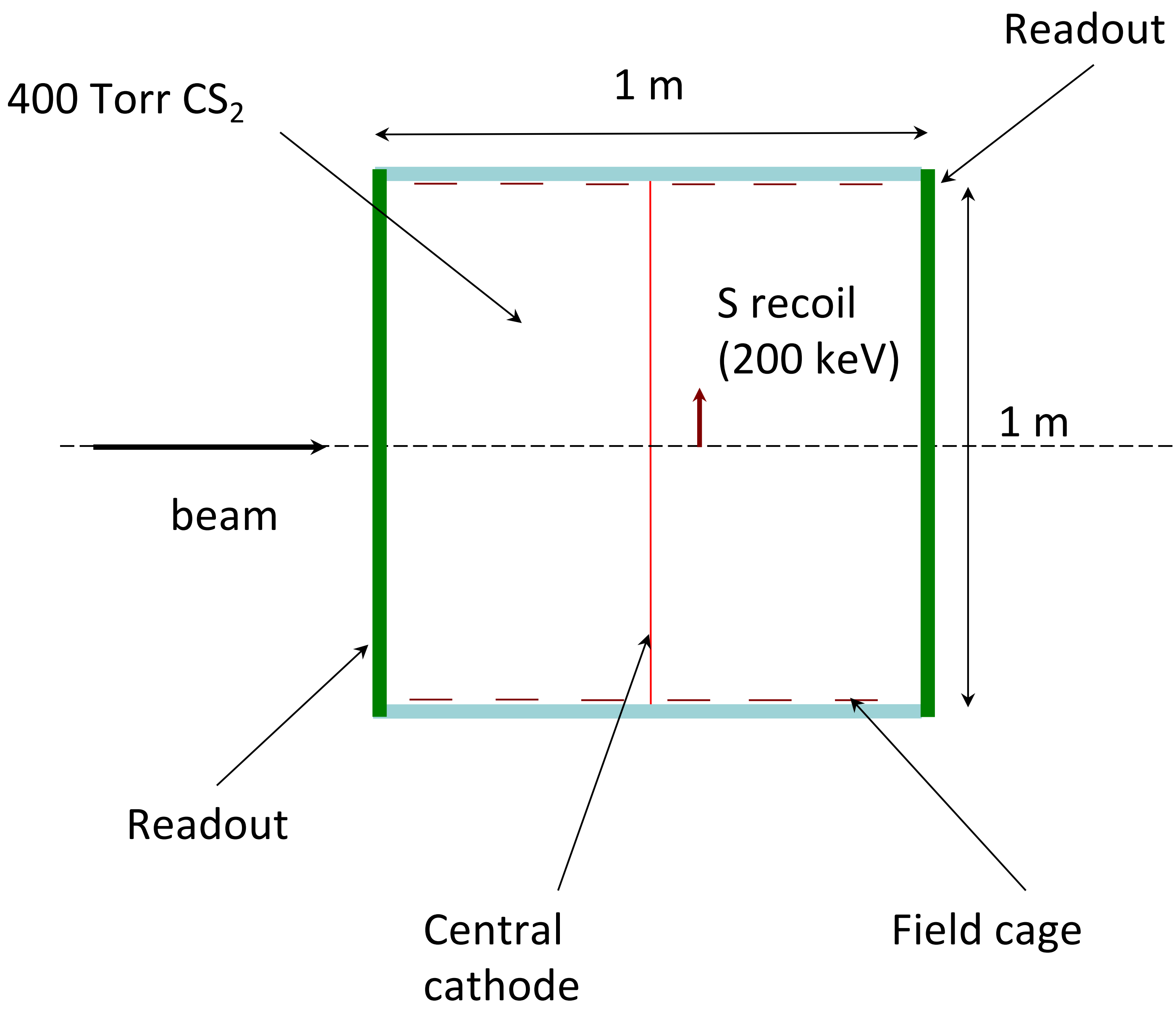
Backgrounds – Predicted

10 m³ year exposure to NuMI LE



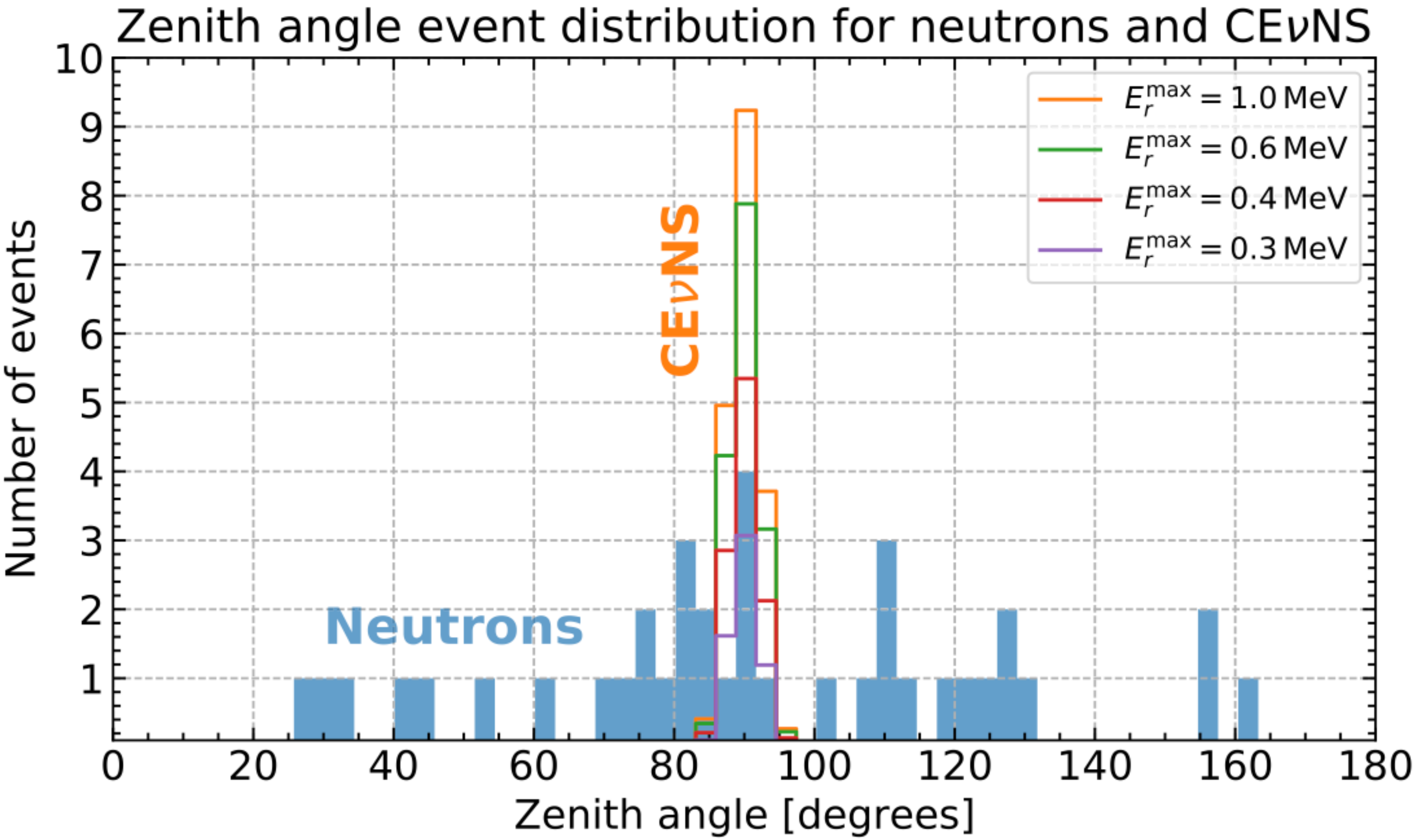
PRD 107, 2023, arXiv:2210.08612, Aristizabal-Sierra et al.

Directionality



Backgrounds - Predicted

10 m^3 year exposure to NuMI LE



PRD 107, 2023, arXiv:2210.08612, Aristizabal-Sierra et al.

Conclusion

- νBDX-DRIFT brings a unique, proven, halo-dark-matter detector to CEνNS research
- A 10 m^3 νBDX-DRIFT detector in the Near Detector hall in DUNE could detect 400 CEνNS events in a 7-year run
- νBDX-DRIFT offers interesting new capabilities and complementarity for CEνNS research
- Measurements of WMA and n distribution available
- NSI, BSM and new physics
- Backgrounds are expected to be under control
- In the near term we hope to deploy an existing 1 m^3 νBDX-DRIFT detector in the NuMI beam at Fermilab to test these ideas out